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A Comparison of Parabolic Equation Models With a Stepwise Coupled Modes Model

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Preface

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Parabolic equation calculations are compared with stepwise coupled mode, COUPLE, calculations for a set of runs for which the two models have overlapping capability. The PE calculations were then extended to consider the additional case of refracting sediment. Normal mode start up fields were used in the calculations. PE models have capabilities differing in the areas of wide angle capability, treatment of the bottom and numerical methods. The intent of this paper is to discuss which of these differences are significant. Calculations were performed at 50 hz. Water depths varied somewhat, but averaged about 150m, corresponding to 3 wave lengths at 50 hz. The dependence of depth with range took two forms. The first consisted of smoothly varying linear segments, the second was the same as the first with a number of spike like irregularities added. Differences are discussed in terms of numerical issues and the physics incorporated in the models.

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A COMPARISON OF PARABOLIC EQUATION MODELS
WITH A STEPWISE COUPLED MODES MODEL

INTRODUCTION

In the comparison of acoustic propagation models it often happens that different models give different answers to the same problem. These differences arise from differing mathematics underlying the models or from differeing numerical techniques in implementing the model on a computer. For ocean acoustic propagation, the wave equation can be approximated by an equation that is parabolic in form. This parabolic equation (PE) has a number of desirable properties, chief among them is that the marching nature of the solution lends itself to introducing changes to the sound speed profile and water depth as a function of range. In this paper we are going to compare two parabolic models: a split step code, PAREQ [1,2] and the implicit finite difference code (IFD/PE) of Lee and Botseas [3] both with the wide angle modification of Thomson and Chapman [4,5]. These codes differ primarily in the numerical technique used in the solution of the PE, i.e., PAREQ uses a split step Fourier method that is computationally efficient, however, it requires that discontinuities in the sound speed profile such as occur at the sea floor be smoothed. The IFD/PE on the other hand can handle discontinuities as long as they are not so large that the underlying assumptions of the parabolic approximation are not violated. In order to emphasize any differences between the two models, we have chosen a range dependent shallow water propagation problem that is strongly bottom interactive.

Since PE's are solved using a marching method, starting fields are important. Robinson and Wood [6] show that if one uses the solution to the normal mode equations for the starting field for PE, then the computations can be done more compactly and the results are more accurate. For these reasons, normal mode starting fields were used in this study.
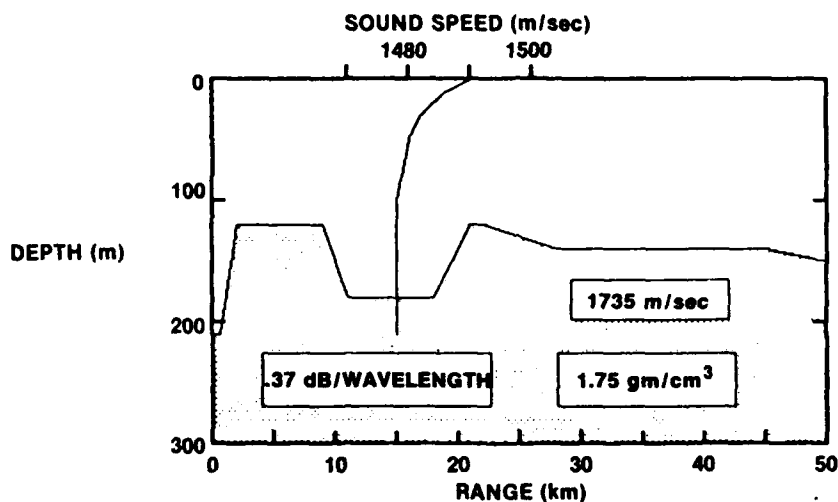
Another comparison was made between PE models and Couple. Couple is a name given to an acoustic propagation model in which normal mode solutions are found in a region where the environment is nearly unchanging. The solutions are made to match at the boundaries between adjacent regions and, in this way, range dependence is introduced. Discussion of the Couple model results for the same environment considered in this paper are given in Evans and Syck [7].

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RANGE DEPENDENT TEST

SOUND SPEED (m/sec)

1480   1500

DEPTH (m)

1735 m/sec

.37 dB/WAVELENGTH   1.75 gm/cm³

RANGE (km)

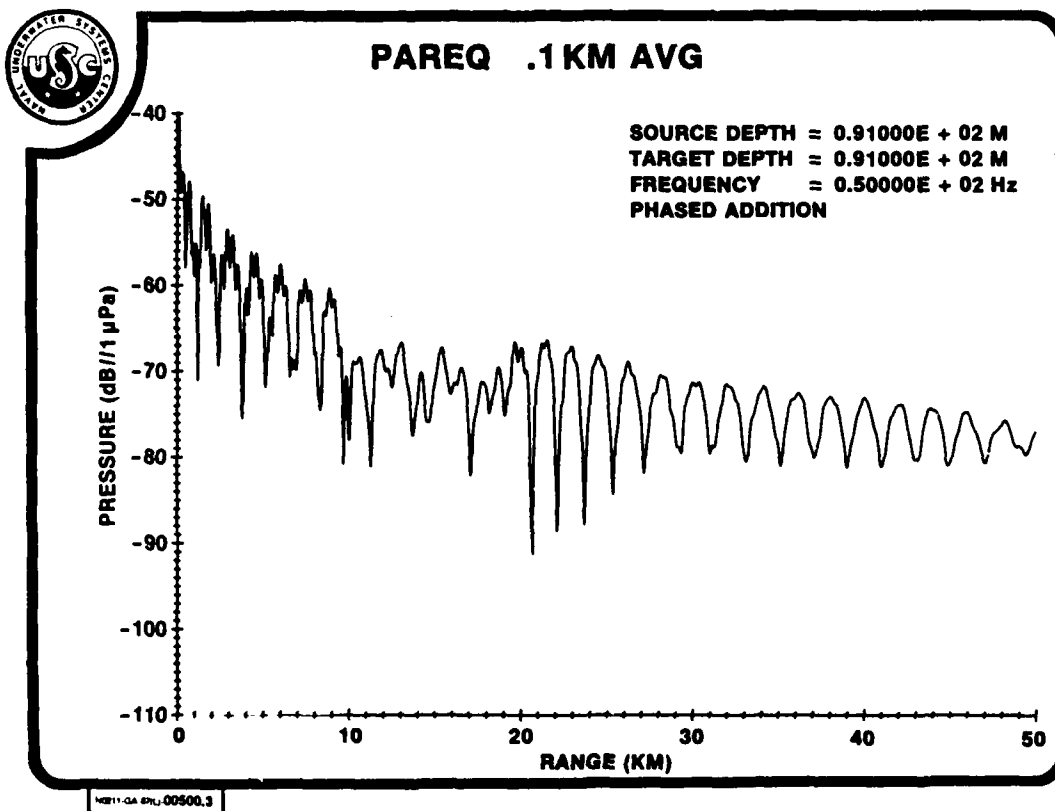N0211-0A-878J-00507

VIEWGRAPH 1

This viewgraph shows the geoacoustic situation for the computations to follow. The problems for the modeler presented here are typical of many shallow water environments.

This environment is one in which we expect strong acoustic interaction with the bottom. In this kind of environment IFD/PE may have some advantages over split step because of the way IFD/PE handles the bottom boundary condition. The first set of comparisons will be made for the case of a constant sound speed sediment. The next set of comparisons will be made for the case of a refracting sediment.
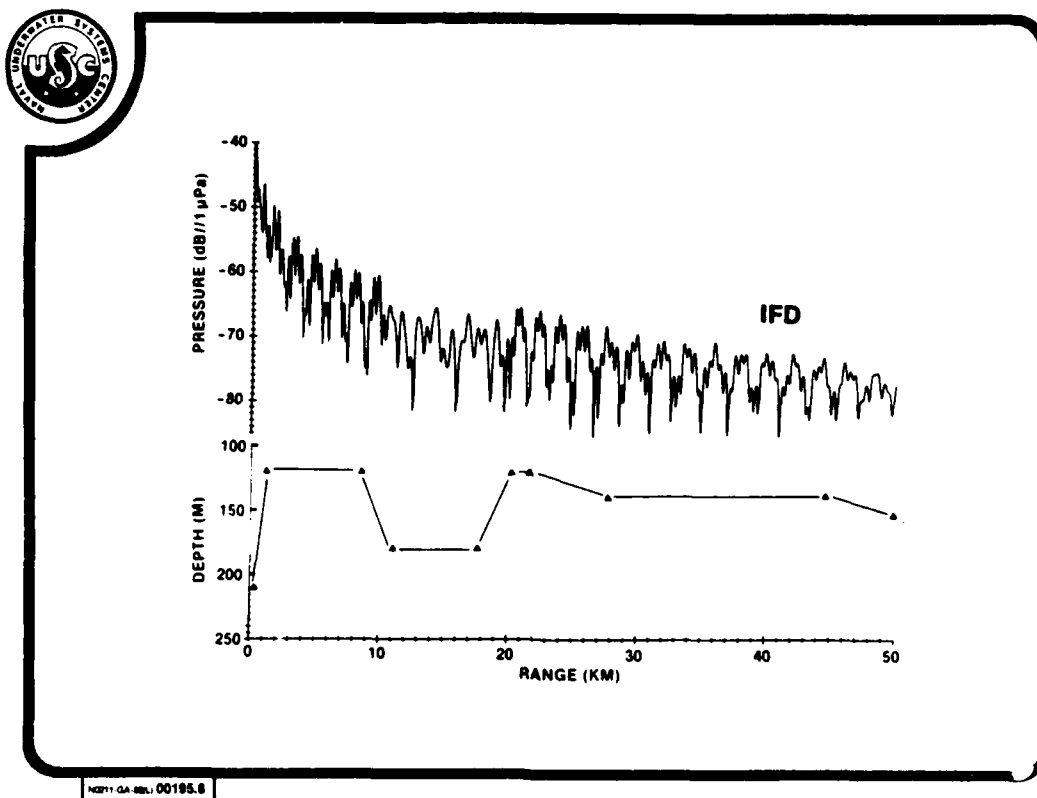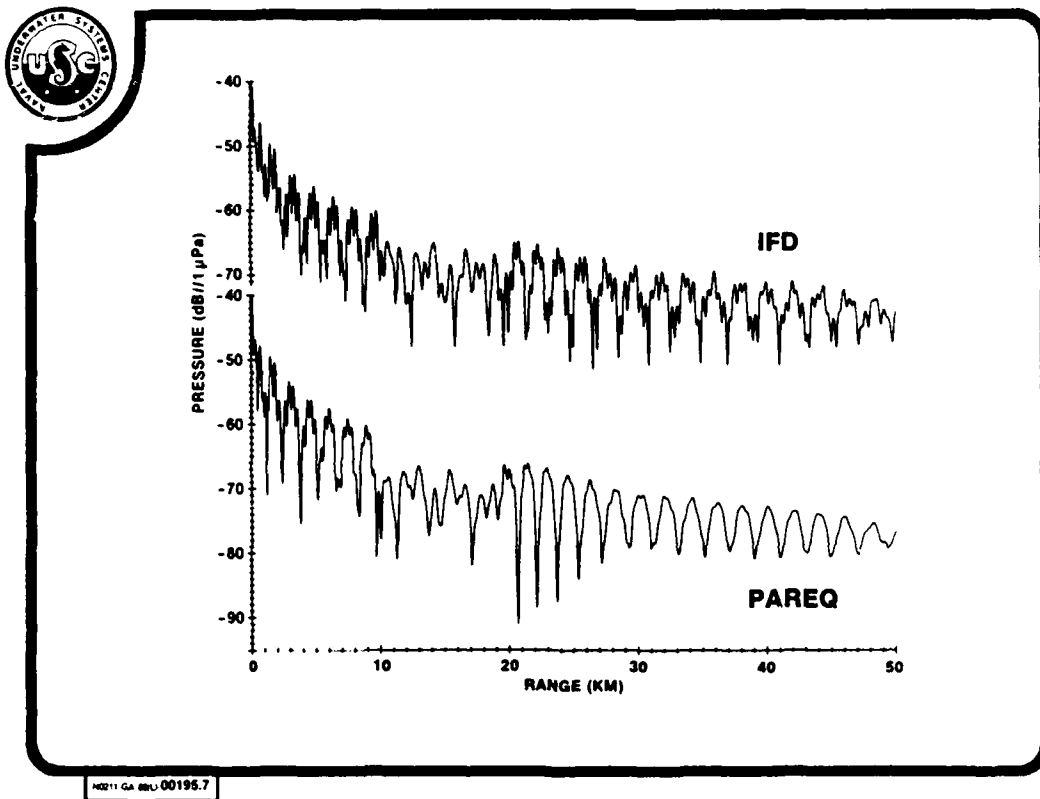
VIEWGRAPH 2

This viewgraph illustrates an IFD/PE run for the environment just presented. The source depth is 91 m with a frequency of 50 Hz and the receiver depth is also 91 m. The source and receiver both have omnidirectional characteristics. Here, we see propagation loss as a function of range with the bottom bathymetry superimposed. In the vicinity of the bathymetric low, 11 to 18 km, we see an increase in loss and the character of the interference pattern changes. This region is followed by a slope enhancement, 18 to 20 km, where a decrease in propagation loss is seen. The region after the slope enhancement is characterized by cylindrical spreading loss.

PAREQ   .1 KM AVG

SOURCE DEPTH = 0.91000E + 02 M
TARGET DEPTH = 0.91000E + 02 M
FREQUENCY   = 0.50000E + 02 Hz
PHASED ADDITION

PRESSURE (dB//1 μPa)

RANGE (KM)

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VIEWGRAPH 3

This viewgraph has the same input model parameters as viewgraph 2, but here the PAREQ model is used. Qualitatively, this run illustrates the same general correlation with bathymetry as IFD/PE. However, at ranges greater than the bathymetric low, the structure in the interference pattern is suppressed.
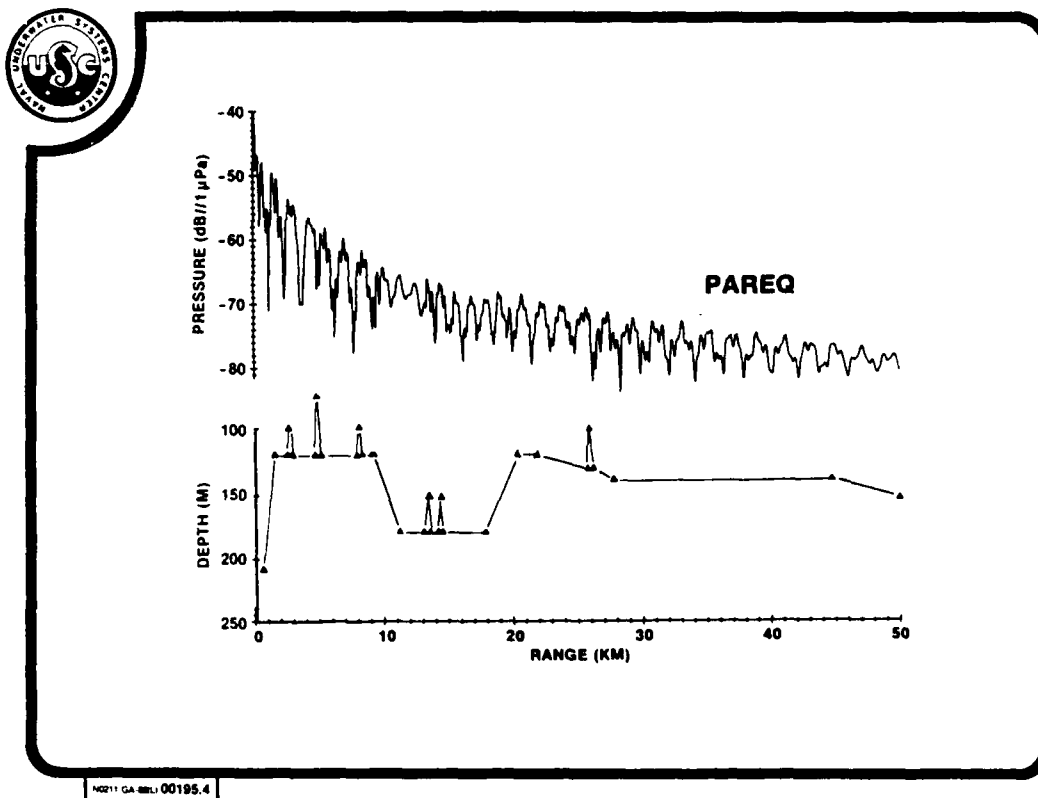
VIEWGRAPH 4

This viewgraph illustrates a superposition of the results from the previous two viewgraphs. The two models show agreement at short ranges (to within about 0.5 dB). Both models predict greater propagation loss in the vicinity of the bathymetric low. Both models exhibit 1/R fall off at long range. In the vicinity of the bathymetric low, there is a phase shift of about 1 km, but the levels are about the same for the two models. At longer range the peaks are 1 to 2 dB higher for IFD/PE.
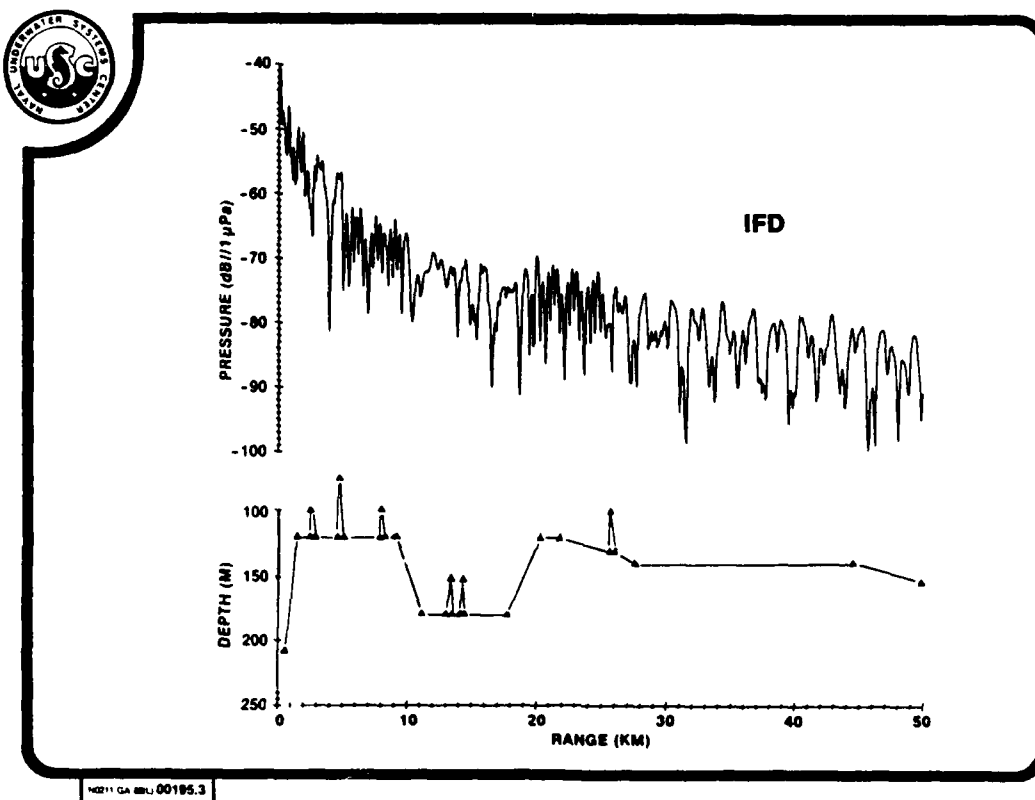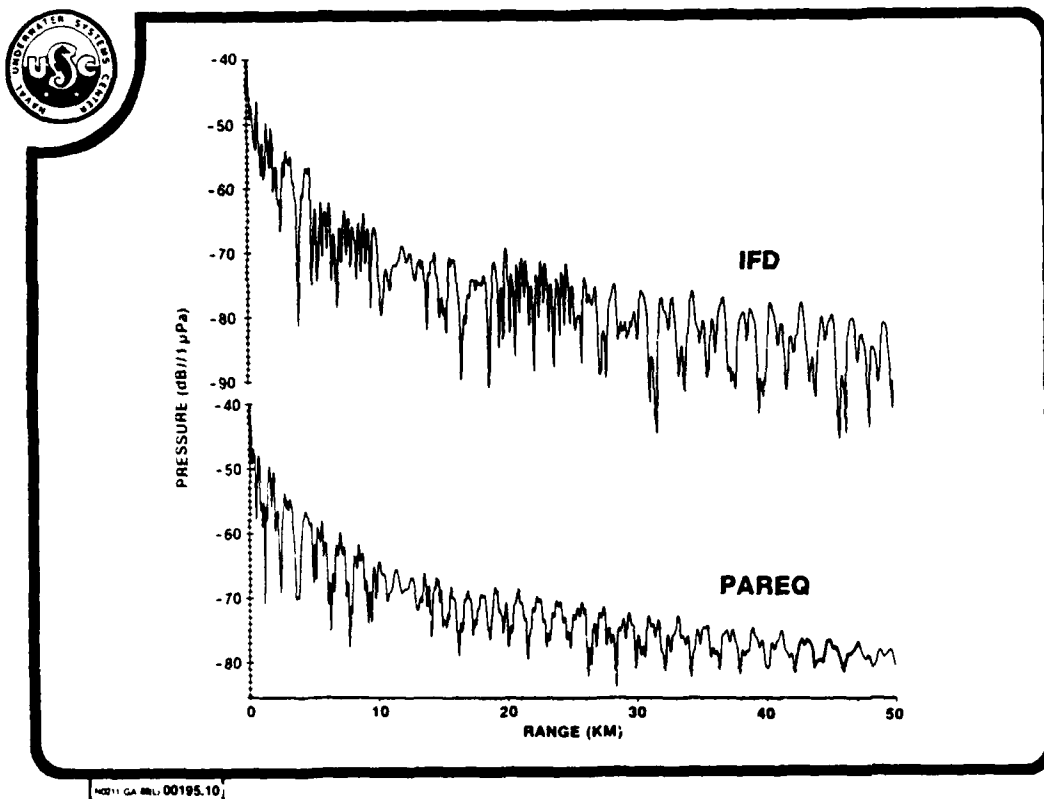
VIEWGRAPH 5

The next two viewgraphs show the effects of additional bathymetric structure in the form of small scale roughness. At long range (greater than 25 km) there is a roughness induced increase in propagation loss of 7 to 8 dB. At a range of 4.9 km, corresponding to the first large bump, there is an increase in propagation loss of about 4 dB and an increase in the structure of the interferences pattern (see viewgraph 2). Another bump at 26 km causes a decrease in structure in the interference pattern. Note the deep nulls at long range. Also, at ranges between 19 and 24 km, we see an increase in the interference pattern structure.

VIEWGRAPH 6

We note the following: in comparing this viewgraph with viewgraph 3 (PAREQ without bumps), the effect of the introduction of small scale roughness on PAREQ is to remove the propagation variation that occurred in the vicinity of the bathymetric low. Also, the long range propagation loss after the bathymetric low (greater than 19 km) illustrates a 2 to 3 dB increase in loss with the presence of bathymetric bumps.
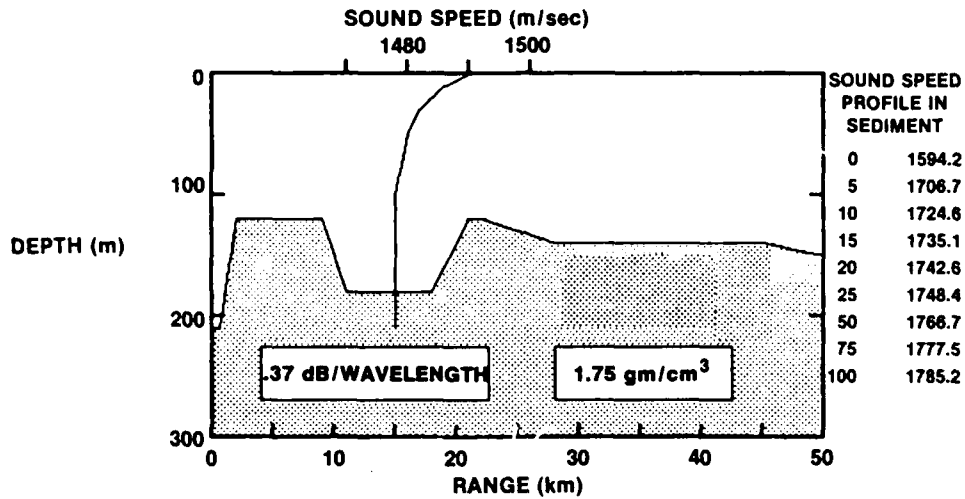
VIEWGRAPH 7

This viewgraph illustrates a comparison of IFD/PE and PAREQ for the case of bottom bathymetric large and small scale roughness. It is apparent that IFD/PE is more sensitive to small scale roughness than is PAREQ. In PAREQ the effect of small scale roughness is to reduce the variability in the interference patterns, when compared to IFD/PE. PAREQ exhibits 4 to 5 dB less loss than does IFD/PE, at ranges greater than 9 km.
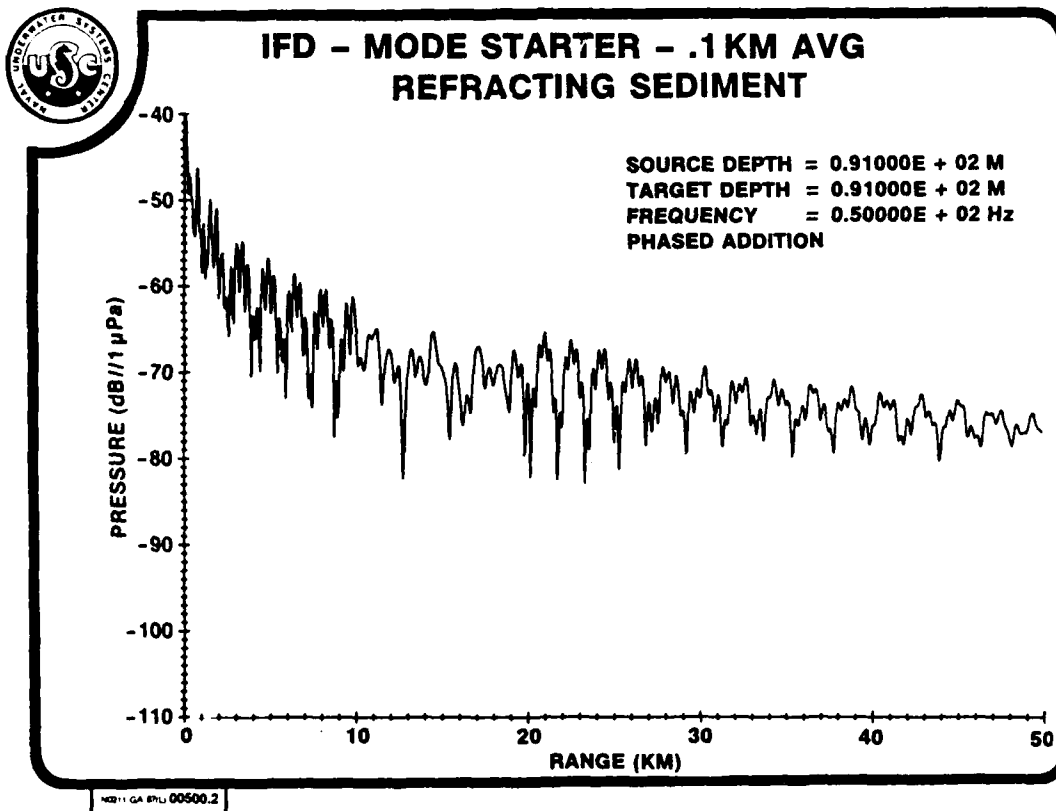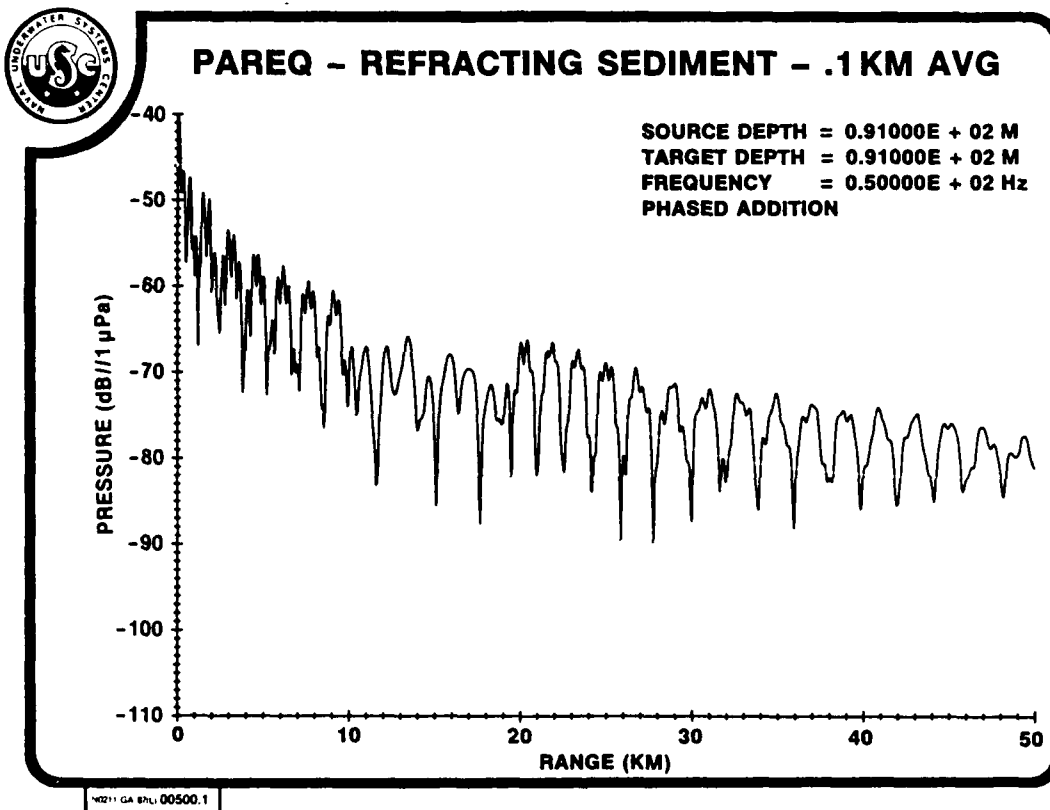
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RANGE DEPENDENT TEST REFRACTION

VIEWGRAPH 8

We now consider a set of comparisons for the case of large scale bathymetric variations with the introduction of a sound speed gradient in the bottom. The gradient creates the potential for sound energy that penetrates the bottom to reemerge in the water volume down range.

IFD – MODE STARTER – .1 KM AVG
REFRACTING SEDIMENT

SOURCE DEPTH = 0.91000E + 02 M
TARGET DEPTH = 0.91000E + 02 M
FREQUENCY   = 0.50000E + 02 Hz
PHASED ADDITION

VIEWGRAPH 9

Here we see a prediction of propagation loss for the refracting bottom
sound velocity case using IFD/PE. The effect of the bottom sound speed
gradient is to change the location of the peaks and nulls in the
interference pattern without significantly changing the propagation loss
(compare with viewgraph 2).

PAREQ – REFRACTING SEDIMENT – .1 KM AVG

SOURCE DEPTH = 0.91000E + 02 M
TARGET DEPTH = 0.91000E + 02 M
FREQUENCY = 0.50000E + 02 Hz
PHASED ADDITION

VIEWGRAPH 10

Similarly, we make a comparison here for the refracting bottom case, but now using PAREQ. At ranges greater than 20 km, we see a shifting of the interference pattern by approximately 1 km and the level for the refracting case is 2 dB lower than the case without refraction (see viewgraph 3). Also, the nulls exhibit more loss for the case with refraction.
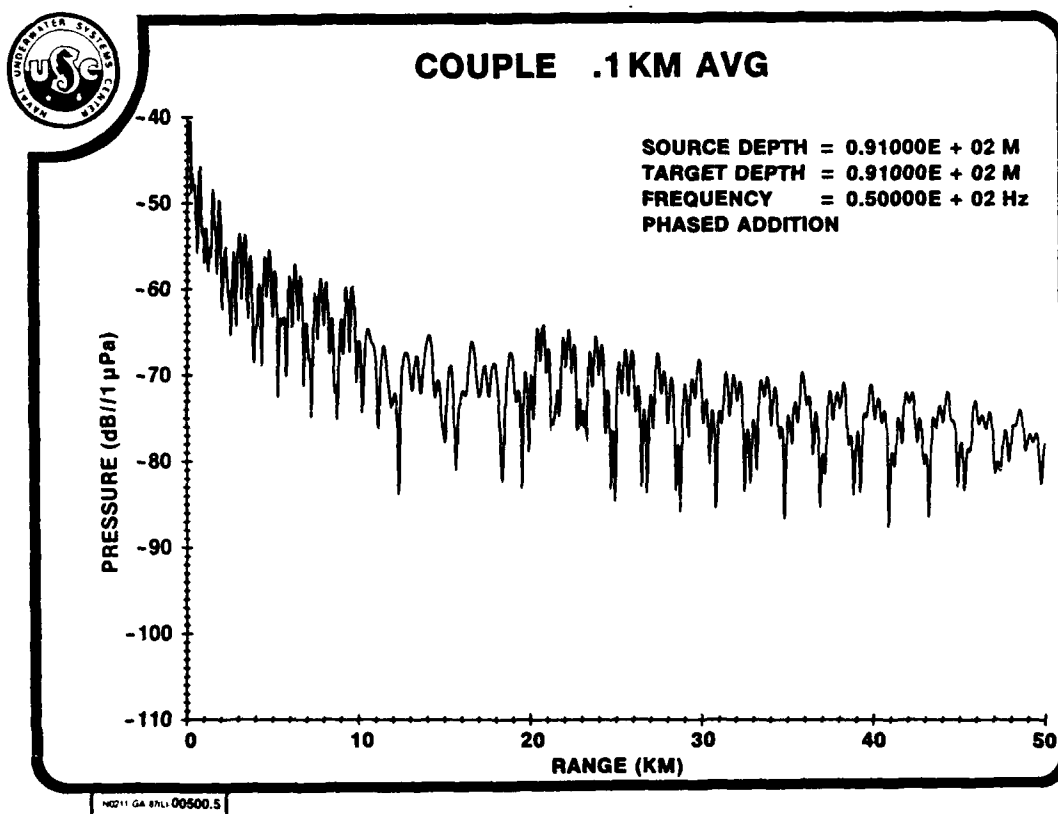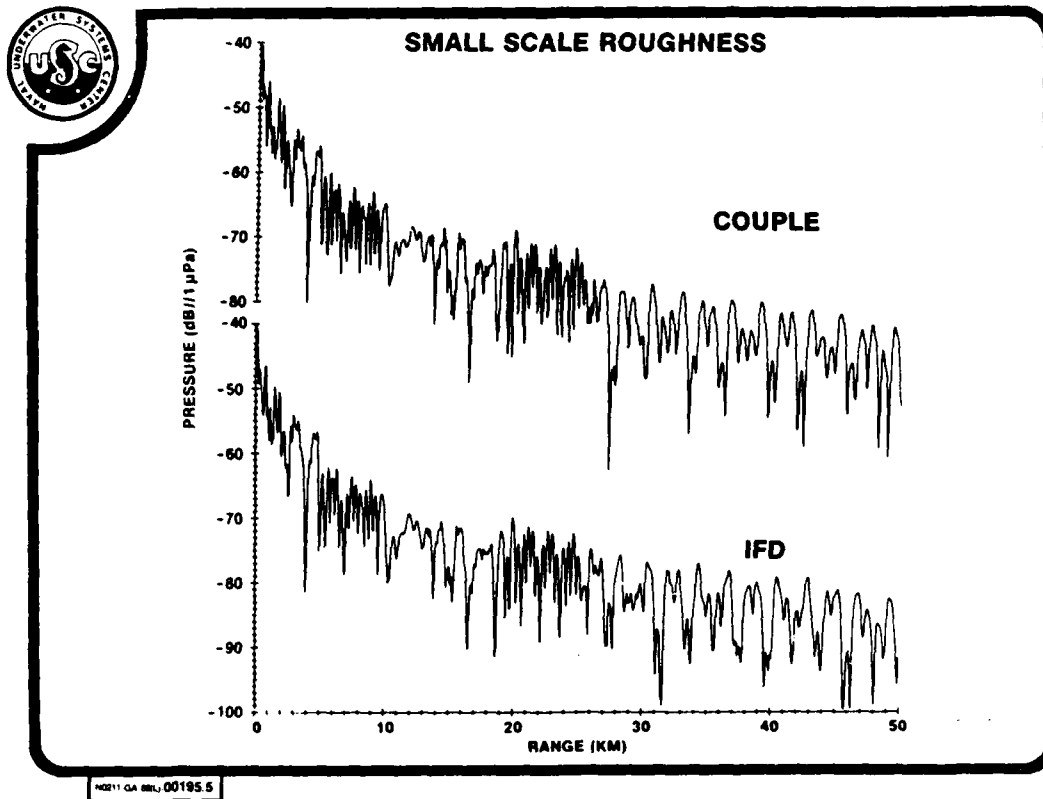
VIEWGRAPH 11

In a paper by Evans and Syck [7], IFD/PE was compared with COUPLE. These comparisons were performed for the case of constant sound speed in the sediment. They compare to within a fraction of a decibel. The major difference between these models is that COUPLE is much more complicated in mathematics and it requires much greater execution time.
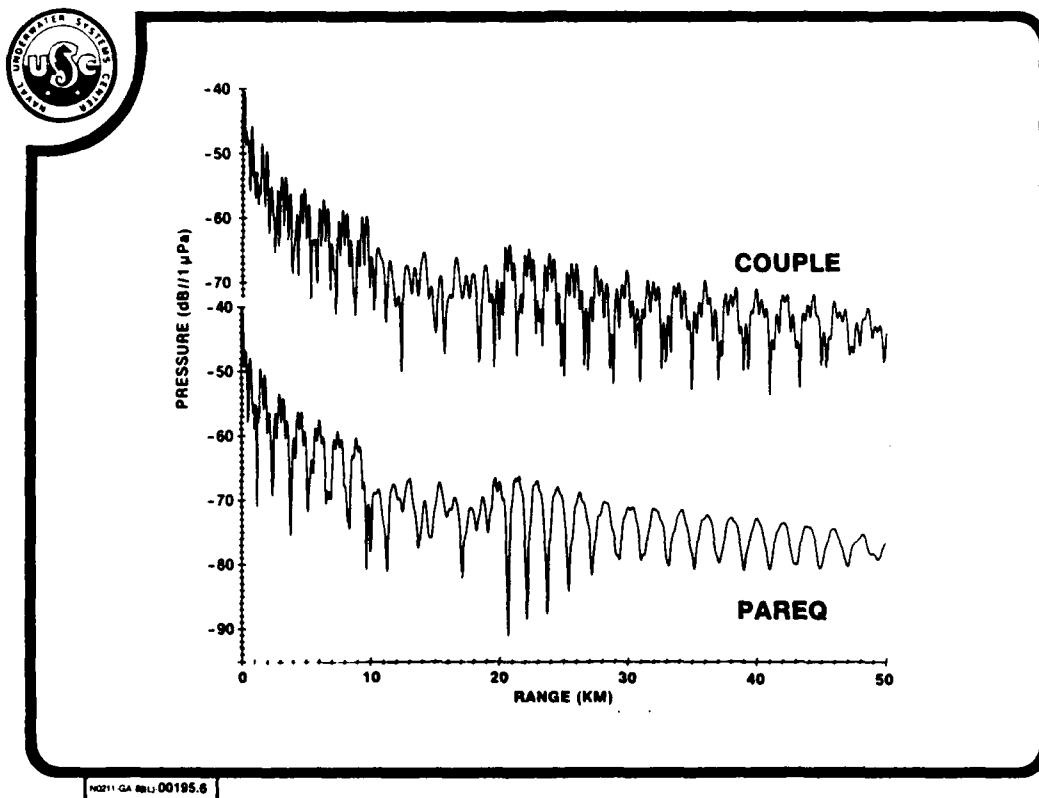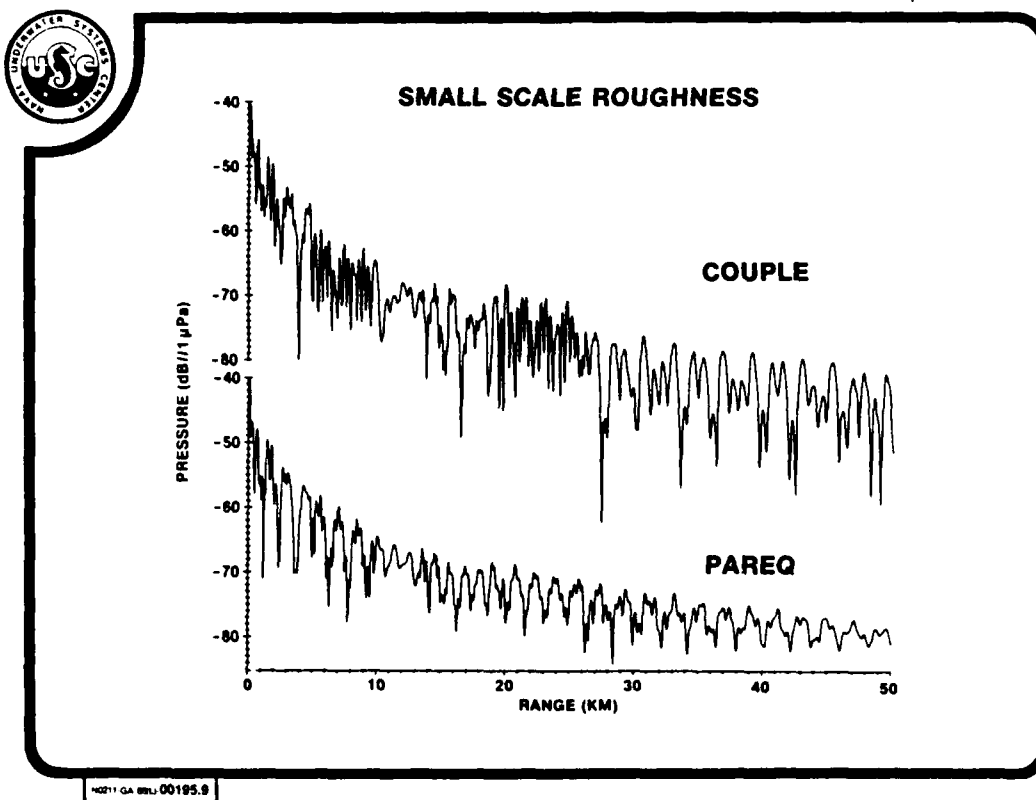
VIEWGRAPH 12

The comments given earlier about the comparisons of PAREQ with IFD/PE also apply here because of the close relationship between COUPLE and IFD/PE. PAREQ predicts greater loss at long ranges (about 3 dB for peak levels) and somewhat less variability. Here COUPLE and viewgraph 3 are overlaid.

VIEWGRAPH 13

Here we see a comparison of IFD/PE with COUPLE for the case of small scale roughness and a nonrefracting bottom. At ranges less than 24 km the agreement in propagation level and structure is excellent. At ranges greater than 24 km, the peaks in COUPLE are 1 dB less than IFD/PE and the nulls are an average 5 dB lower with COUPLE. Also, a small phase shift is seen, approximately 0.21 km.

SMALL SCALE ROUGHNESS

VIEWGRAPH 14

Here we see a comparison of COUPLE with PAREQ for the case of small scale roughness and nonrefracting bottom. COUPLE exhibits greater loss than PAREQ, approximately 4 to 5 dB, at ranges greater than 24 km. Also at these ranges the propagation loss at the null locations is 20 dB greater for COUPLE.

CONCLUSIONS

- IFD/PE COMPARES WELL WITH COUPLE IN NON-RETRACTING CASE

- PAREQ PREDICTS GREATER PROPAGATION LOSS IN NON-REFRACTING CASE

- PAREQ HAS PHASE DIFFERENCES AT LONG RANGE

- REFRACTING BOTTOM FILLS IN NULLS AT LONG RANGE

- SMALL SCALE ROUGHNESS COMPLICATES MODAL PROPAGATION STRUCTURE AND ALTERS LEVEL SIGNIFICANTLY

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VIEWGRAPH 15

CONCLUSIONS:

- IFD/PE compares well with COUPLE in the nonrefracting case.

- There are phase differences at long range with PAREQ that are not present in the IFD/PE results.

- The effect of a refracting bottom is to fill in the nulls at long range.

- Small scale roughness complicates model structure and alters levels significantly (7 or 8 dB).

The point of this study is to compare model performance in a calibrated, realistic environment. In some cases it is surprising how well the different models compare given differences in mathematical formulation. This work is quite distinct from comparison of model data to measurements. While that must also be done, this study is a comparison of models with one another.

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